CSIRO PUBLISHING

www.publish.csiro.au/journals/env J. M. Cainey, *Environ. Chem.* **2007**, *4*, 141–142. doi:10.1071/EN07010

Understanding the origin of clouds

Jill M. Cainey

Bureau of Meteorology, Cape Grim Air Pollution Station, PO Box 346, Smithton, Tas. 7330, Australia. Email: j.cainey@bom.gov.au

Clouds are an important part of our atmosphere and they have a critical role in controlling the amount of the sun's energy that reaches the earth's surface. Clouds can have a cooling effect on the atmosphere, which counteracts increases in temperature caused by climate change.[1] Understanding exactly how clouds impact on our climate and ensuring that we can accurately model the current role and extent of clouds is critical to determine how any changes in climate will affect clouds and how clouds will affect climate in the future.

Clouds consist of many drops of liquid water and these droplets form when water vapour condenses on the surface of a tiny particle. The sources of these particles in the atmosphere are many and varied. Some are generated from the surface of the land or ocean by wind action, and some of these primary particles can act as cloud condensation nuclei (CCN).[2] There are also several natural processes that emit gases, which then react in the atmosphere to form secondary particles. This includes the emission of gases from plankton and seaweed in the ocean and plants on land. Man's activities, such as the burning of fossil fuels can also result in the production of particles either directly or through precursor gases.

There is a complicated interaction between existing particles and gases in the atmosphere. Larger particles can mop up the precursor gases before they can form a particle, which limits the role for secondary particle formation.[3] Even clouds themselves have a very important role in reactions between gases and between particles and gases.[4]

The CLAW Hypothesis[5] was published in 1987 and stated that plankton in the ocean emitted dimethyl sulfide (DMS), which once in the atmosphere eventually forms tiny sulfate particles that could act as CCN. It was suggested that plankton emitted more DMS when under stress from higher sea surface temperatures and so more CCN and clouds would result, which created a feedback loop to limit warming.[5] Many studies have shown that the seasonal cycles of DMS, sulfate particles and CCN numbers are strongly correlated.[6] However, other studies have shown that DMS-derived sulfur dioxide is removed by larger particles before it can form tiny sulfate CCN.[3]

DMS isn't a major source of CCN in the marine boundary layer,[7] but has an important role in modifying the chemistry of new particles and a role in nucleation in the free troposphere,[8] but is only a limited contributor to nucleation in the marine boundary layer.[7] At Mace Head, Ireland, the local kelp, *Laminaria digitata* is a significant source of iodine, which acts as an initiator for new particle formation.[9] When the kelp is stressed at low tide, around midday, large particle formation events are observed and clearly the kelp has a very important role in making new particles at Mace Head.[9–14]

In February 2006 the Precursors to Particles (P2P 2006) campaign occurred at the Cape Grim Baseline Air Pollution Station, Tasmania. The aim of P2P 2006 was to assess the role of the local kelp, *Durvillaea potatorum*, in emitting iodine and in forming new particles that could act as CCN. Particle measurements during P2P 2006 showed no new particle events in either clean marine or post-frontal air.[15] Biological, gas and particle measurements on the beach 94-m below the Station showed only very small increases in particle numbers and methyl iodide[15,16] and no elevation over background levels for some of the other potential precursor gases, such as IO, OIO and DMS.[15,17]

To better understand the differences between the kelp at the two sites, samples were studied in a chamber and *Durvillaea potatorum* would only produce particles when exposed to very high, unnatural levels of ozone.[18] The particles that resulted from exposure to ozone were unusual and composed of a highly volatile aromatic.[18] Additional transmission electron microscope grid samples of particles in clean marine air were collected and most of these particles originated from the surface of the ocean surface,[19] with particle growth the result of the addition of sulfate.[19,20]

Material from the surface micro-layer of the ocean modifies aerosol chemistry[21] and at Cape Grim appears important for providing nucleating centres.[19] The chemistry (and biology) of primary particles derived from the surface micro-layer needs to be monitored and these measurement techniques need to be used to verify satellite measurements of the same parameters, since remote sensing gives better coverage of the ocean than can be achieved by cruises and coastal stations. Sampling of the ocean surface micro-layer to determine its content is needed and a better understanding of the relationship of wind speed to the generation of particles from the ocean's surface is required,

Jill Cainey completed her PhD at Monash University and CSIRO Atmospheric Research, studying the atmospheric sulfur cycle at Cape Grim in Tasmania. After 5 years at NIWA, New Zealand, assessing the sulfur cycle, using sulfur isotopes, she returned to Australia in 2003 to manage the Cape Grim Baseline Air Pollution Station. Her recent work has focussed on the role of micro- and macro-algae in initiating particle formation, organising a campaign "Precursors to Particles 2006" to assess the contribution of local kelp to particle events and continues to be an atmospheric scientist who is not afraid to get her feet wet.

1448-2517/07/030141

particularly to allow better modelling of cloud formation and radiative impacts in a changing climate.

The role of plankton in initiating new particle formation from DMS is limited by the presence of much larger sea salt particles that absorb sulfur dioxide.[22] The work at Cape Grim suggests that the role of kelp in promoting new particle formation is limited, but *Durvillaea potatorum* emits iodine and this will have an impact on atmospheric and aerosol chemistry.[15] Only limited work at other sites that support *Laminaria digitata* has been performed and have only assessed precursor gases.[23] The work at Cape Grim indicates that further work is required at other locations and on other macro-algae to better understand the global importance of the processes identified at Mace Head.

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Manuscript received 30 January 2007, accepted 16 May 2007